Artículo de investigación

Unmanned aerial vehicles for estimation of vegetation quality

Применение Беспилотных Летательных Аппаратов Для Оценки Качества Растительности

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Abstract

The use of Earth remote sensing (ERS) in agriculture is related with inventory of arable areas, detection of soil erosion, bogging. At present great attention is paid to studies devoted to determination of productivity of arable areas based on ERS data under various climatic conditions. Satellite images are characterized by certain drawbacks such as low resolution, impossibility to acquire images from behind clouds. A promising approach to obtain high precision maps is the use of unmanned aerial vehicles (UAV).

The degree of crop development is estimated by their NDVI which is used in numerous photometric instruments for diagnostics of plant nitrogenous nutrition. With this aim, the UAV camera detects plant reflection intensity of sunlight or induced light in red (P NIR) and infrared (P RED) spectra. Thus, it becomes necessary to determine mechanisms and interrelation of vegetation index which would permit to obtain data on crop productivity on the basis of data from UAV.

Аннотация

Использование данных дистанционного зондирования Земли (ДДЗ) в сельском хозяйстве связано с инвентаризацией сельхозугодий, обнаружением эрозии почвы, заболачивания. В последние годы большой интерес приобретают исследования, направленные на выявления урожайности сельскохозяйственных культур с данными ДДЗ в различных климатических условиях. Использование космических снимков имеет ряд недостатков, таких как: низкое разрешение, невозможность получения их из-за облаков. Одним из перспективных путей решения получения высокоточных карт является применение беспилотных летательных аппаратов (БПЛА). Для оценки степени развития посевов обычно применяют их вегетационный NDVI, который используется во многих фотометрических приборах для диагностики азотного питания растений. Для этого в фотокамере БПЛА предусмотрена фиксация интенсивности отражения растениями солнечного или

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Keywords: ERS, aerial photography, UAV, vegetation index, vegetation, crop productivity.

индуцированного света в красной (P NIR) и инфракрасной (P RED) областях спектра. Исходя из этого возникает необходимость проведения в исследований по выявлению механизмов и взаимосвязи вегетационного индекса, что позволит получать информацию о продуктивности сельскохозяйственных культур, используя данные с беспилотного летательного аппарата.

Ключевые слова: ДДЗ, аэрофотосъемка, БПЛА, вегетационный индекс, растительность, урожайность.

Introduction

Winter wheat is one of the major crops for Tambov oblast, its productivity mainly depends on autumn development and wintering of crops. Their normal growth is related with external factors (temperature, moisture content, light) and agrotechnical procedures. Under proper treatment, winter crops are developed better and survive better under unfavorable climatic conditions in winter and early spring.

Acquisition of information about physiological state of plant is a difficult process, and due to extensive surveying areas, it is not precise enough. These targets can be achieved by optical estimation methods which are characterized by fairness and efficiency.

Advances of theoretical concepts of nitrogenous nutrition and technical capabilities to diagnose its level make it possible to develop approaches and procedures for maximum automation, that is, robotization, both of detection of demand of crops for optimization of their mineral nutrition and of methods of its adjustment.

The vegetation diagnostics by photometric methods is based on dependence of their nitrogen supply on chlorophyll content in leaves, its photo activity (fluorescence). Hence, the main principle of diagnostic photometry is detection of chlorophyll content in leaves or crops, or fluorescence intensity (Eroshenko, 2011).

The interrelation between intensity of green color of leaves and the level of their mineral nutrition has long been known and applied by European agronomy for diagnostics in the 19th century. However, if not long ago the vegetation diagnostics was based mainly on visual and chemical methods, then at present these methods are replaced or supplemented by instrumental procedures including robotics and remote sensing by UAV.

This work is aimed at: establishing interrelation between productivity of winter wheat and NDVI in Tambov oblast.

Materials and Methods

In accordance with Federal airspace regulations of Russian Federation approved by Decree No. 138 of the Russian government dated March 11, 2010, unmanned aerial vehicle (UAV) is an aerial vehicle without humans on board and controlled automatically, or by operator from control center, or by combination of the mentioned methods.

The ERS targets in agribusiness business are as follows (Astapov et al., 2018):

- Precise detection of boundaries;
- Revealing unused areas;
- Detection of degrading sites;
- Arrangement of soil maps;
- Arrangement of relief maps;
- Development of 3D model of field;
- Territory inventory;
- Observation of crop state at various stages of growth and development;
- Monitoring of melioration and hydro technical facilities;
- Determination of crop heterogeneity.

Space survey disadvantages are as follows: low resolution of satellite images; covering of some sites by clouds.

At present there are about 160 variants of vegetation indices. They are selected empirically on the basis of known peculiarities of spectral reflection ability of vegetation and soils. Most vegetation indices are calculated by two most stable (independent on other factors) segments of plant reflection capacity. The red spectrum (0.62 - 0.75 µm) stands for maximum solar radiation absorption by chlorophyll, and the near infrared spectrum (0.75 - 1.3 µm) determines maximum energy reflection by leaf cell structure. That is, high photosynthetic activity, related usually with high vegetation phytomass, leads to lower values of reflection coefficients in the red spectrum and to higher values in the near infrared spectrum. As is well-known, the ratio of these indices makes it possible to distinguish between vegetation and other objects (Fig. 1).

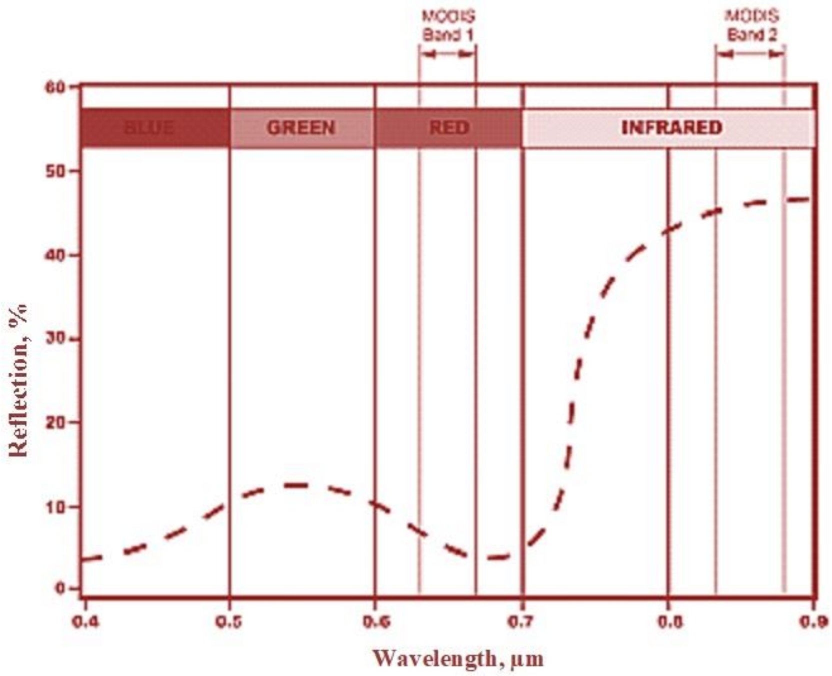

Figure 1. Sunlight reflection by plants

The most widely used vegetation index is NDVI (Normalized Difference Vegetation Index) which can be applied for estimation of development of plant biomass during vegetation (Storchak, 2016). NDVI is calculated by the sum and difference of reflections in red and in near infrared ranges:

NDVI = (ρNIR – ρRED)/(ρNIR + ρRED),
where ρNIR is the reflection coefficient in near infrared spectrum, ρRED is the reflection coefficient in red spectrum.

The range of absolute NDVI values is from–1 to +1 (Fig. 2). For vegetation the index is positive (from 0.2 to 0.9); the higher is the green phytomass of plants during measurements, the closer is the NDVI to unity. NDVI is a relative index, it does not show absolute values of biomass of green leaves (for instance, in t/ha), however, it is possible to estimate reliably the degree of crop development (Eroshenko, 2011; Andrianova, Yu.E., Tarchevskii, 2000).

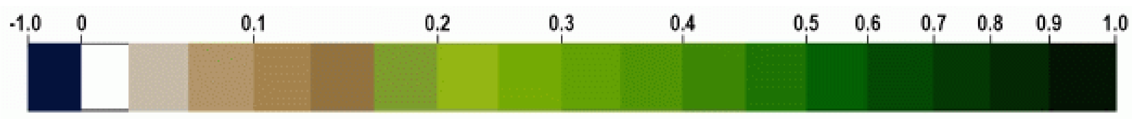

Figure 2. NDVI color scale

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NDVI is continuously varied during growth, flowering, and ripening periods. At the start of vegetation period it increases intensively, then in the flowering period it stops, and then during ripening NDVI decreases. Depending on soil fertility, weather conditions, and cultivation procedures, the biomass development rate will vary. Thus, average NDVI can be used for estimation of crop state during vegetation: in some fields crops develop faster (better), in other – slower (worse) (Maselli, Rembold, 2001).

NDVI characterizes main performances of existing vegetation:

- Productivity (variations in time).
- Biomass.
- Moisture content and mineral (organic) saturation of soil.
- Evaporation capacity.
- Amount of precipitations.
- Capacity and properties of snow cover.

The most accurate forecast of crop harvest on the basis of NDVI can be made when it reaches its maximum. For instance, for winter wheat cultivated according to intensive technology, the maximum NDVI is 0.80–0.88. Maximum NDVI is generally achieved at the start of earing stage (Ferwerda, Skidmore, Mutanga, 2005).

Equipment

Arable areas are surveyed using DJI Inspire 1 2.0 quadrocopter, it is controlled remotely by specialized application on tablet PC. The quadrocopter is UAV with four lifting propellers located at the corners of flying platform (Fig. 3). The propellers are driven by electric motors powered by on-board batteries. The quadrocopter is equipped with automatic pilot receiving GPS and GLONASS signals which supports its orientation and high precision flights along preset routes. Flight route and parameters are stored in the quadrocopter memory.

Figure 3. DJI Inspire 1 2.0

Quadrocopter performs recording from the distance up to 500 m (in some cases the distance to the target can be decreased to minimum allowable). In addition, quadrocopter can provide IR recordings. The flight time is about 18 min under normal weather conditions. Video signal is transmitted via digital channel in HF format and stored on removable drive. DJI Inspire specifications are summarized in Table 1.

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Model	T601
Weight (with battery)	2,935 g
Maximum takeoff speed	5 m/s
Maximum horizontal speed	22 m/s (Atti mode, w/o wind)
Maximum takeoff height above sea level	500 m
Maximum flight time	About 18 min
Allowable operation temperature	From 0°C to 40°C
Dimensions	438×451×301

Table 1. Specifications of DJI Inspire 1 2.0

Some drawbacks should be considered during operation:

- Flights are impossible in bad weather.
- Operation of on-board systems can be interfered by existing communication and electricity facilities (high voltage lines, radio towers, communication cables, etc.).

Photo and video recordings are performed using DJI Zenmuse X3 gimbal with NDVI spectral camera (Fig. 4) for DJI Inspire 1 2.0.

DJI Zenmuse X3 is a high quality 4K camera in the form of smoothly rotating "eye". The main feature is that the device is combined with Zenmuse H4-3D gimbal on the basis of brushless motors. The gimbal was developed by DJI experts. It provides smooth recording around its axis even in the case of vibrations and sharp motions.

Figure 4. DJI Zenmuse X3 gimbal with NDVI spectral camera

Zenmuse X3 camera transfers video via radio channel and is controlled not only from individual remote control panel if it is supplied, for instance, with Inspire 1, but also from smartphone with any OS (or tablet PC) by DJI GO application which facilitates various recording modes and parameters as well as instant image editing with web publishing. Camera picture is transmitted in real-time mode to table PC or smartphone. At resolution of 1,080p the camera supports recording up to 120 frames per second, and at 4K – up to 30. Image details are very high, which is quite obvious for 4K, image portions can be cropped. The main specifications of DJI Zenmuse X3 gimbal with NDVI camera are summarized in Table 2.

Item	Description	Units
MATRIX		
1	Size	6.17×4.55 mm
2	Type	CMOS
3	Effective pixels	12.4 Mp
4	ISO range	100-3,200
5	Spectral range	(0.63-0.69 μm), (0.76-0.90 μm)
PHOTOSURVEYING PARAMETERS		
1	Max. image resolution	12.4 Mp
2	Camera speed	7 frames per second
3	Exposure range	8-1/8,000 s
4	Dynamic range	-3~+3, 1/3
5	Exposure compensation correction	By default

Table: 2. Specifications of DJI Zenmuse X3 NDVI

Results and Discussion

Photogrammetric processing of images using specialized software provides digital terrain model of arable areas. On their basis, the 3D models of field elements were obtained. Aerial survey of arable areas was performed in Michurinsk district owned by Michurinsk State Agrarian University. The flight region is illustrated in Fig. 5. Natural and climatic conditions of the considered site are summarized in Table 3.

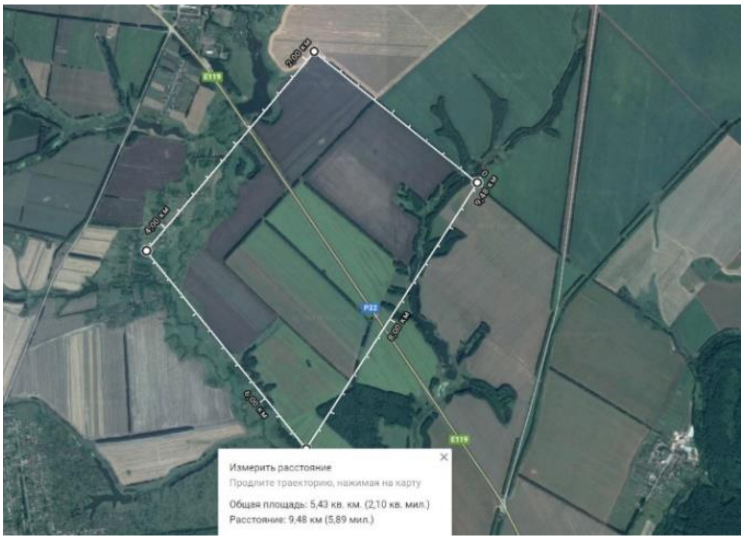

Figure 5. UAV flight region

The coordinates of flight region are as follows:

1) 53°01'32.9"N 40°31'55.2"E
2) 53°00'55.0"N 40°33'11.1"E
3) 52°59'31.3"N 40°31'55.7"E
4) 53°00'35.3"N 40°30'30.8"E

Field surface area:	61 ha
Soil type:	typical chernozem
Relief:	plain
Climate:	moderately continental
Sum of active temperatures at the date of image acquisition:	455°C
Multi-year average:	744°C
Total precipitations from March 1, 2018 at the date of image acquisition:	37 mm
Multi- year average for the same period:	32 mm

Table 3. Natural and climatic conditions

Mironovskaya 808 winter wheat is cultivated at the considered site. Its properties are summarized in Table 4.

Originator:	Michurinsk State Agrarian University
Crop breeder (company, applicant)	Mironovka Institute of Wheat
Registration year	1963
Spike type	unbearded
Maturity group	mid-ripening
Cold resistance:	above average
Drought resistance	above average
Lodging resistance	high
Shedding resistance	high
Disease resistance	middle
Grain quality	strong

Table 4. Mironovskaya 808 winter wheat

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Flight results in the form of aerial images are added to dedicated software: Agisoft PhotoScan, where they are stitched to produce aerial plan in WGS84 coordinate system (Nikitin, Astapov, 2018).

High attention is paid to precision during overall data processing. UAV is adjusted so that it is always possible to analyze the acquired data in the case of emergencies. It can be seen that UAV provides high overlapping between images, which facilitates viewing of one point from 12 images at different angles (Fig. 6). The image angles and position of multispectral camera with regard to Earth can also be estimated (Prishutov et al., 2018).

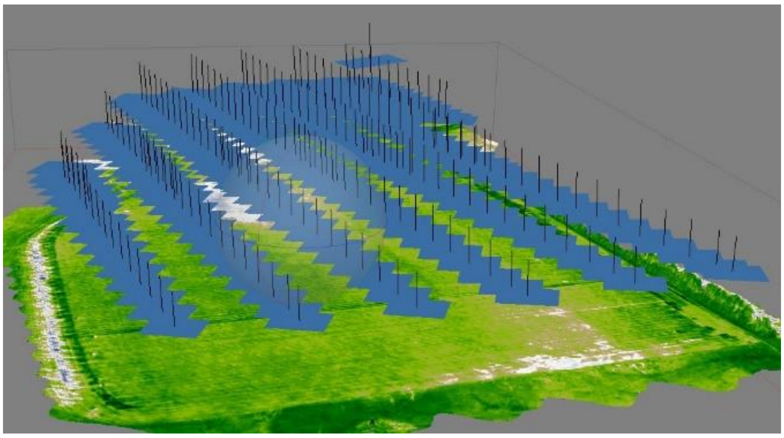

Figure 6. Aerial photograph layout

After aerial image processing, it is possible to observe the degree of coverage, its green phytomass, general state of vegetation (Fig. 7), it becomes possible to calculate absolute value of agriculture index according to calibrated scale for further forecast of crop development.

Figure 7. Vegetation quality (NDVI)

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After procedures at the considered arable areas, it was detected that a portion of crops was in depressed state due to drowning and asphyxiation during prolonged water stagnation after spring floods; in addition, blind creeks were observed which promoted removal of fertile soil layer towards the nearest water source. At these sites, the NDVI was lower than that of neighboring healthy vegetation. There were sites where vegetation was characterized by low index due to inadequate agrotechnical measures (Fig. 8).

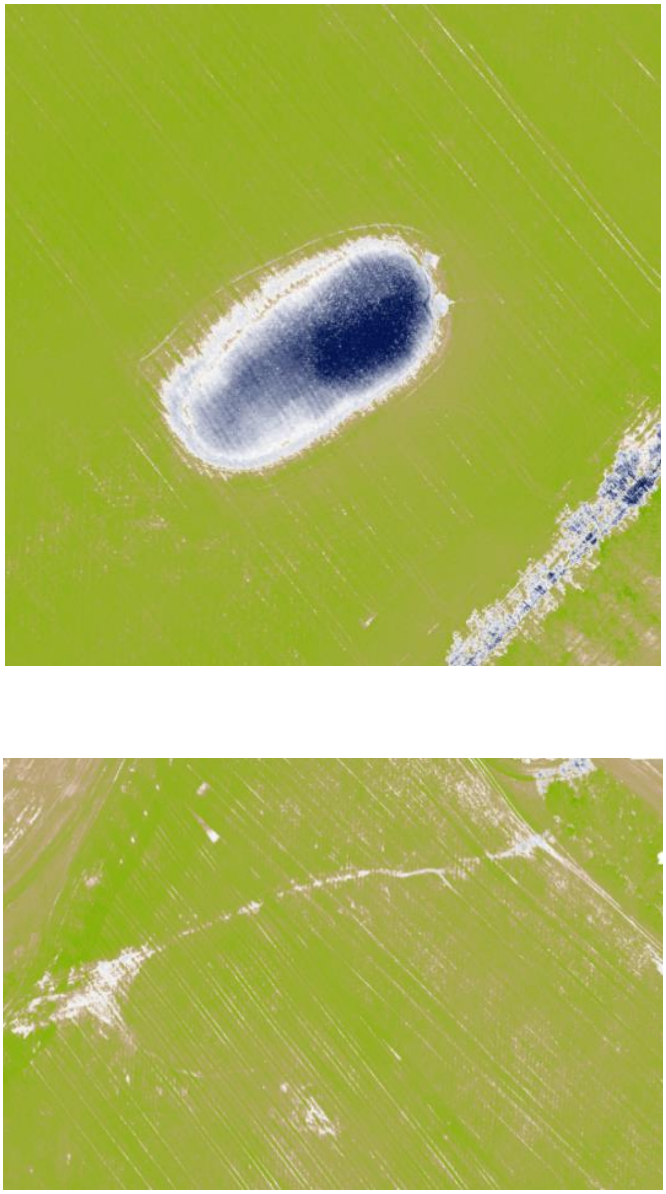

Figure 8. Problem areas

Therefore, the vegetation index of winter wheat crops calculated by remote sensing data reflects grain harvest formation. Average NDVI at the considered field in 2018 was 0.6–0.65, this index is sufficiently informative for estimation of crop physiological state and predictions of crop productivity.

Regression models of winter wheat harvest as a function of NDVI in vegetative–generative

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period were plotted (Fig. 9). Thus, obtained models are characterized by good fidelity.

Therefore, the coefficient of approximation of the developed model is 0.83, and the coefficient of correlation is 0.81.

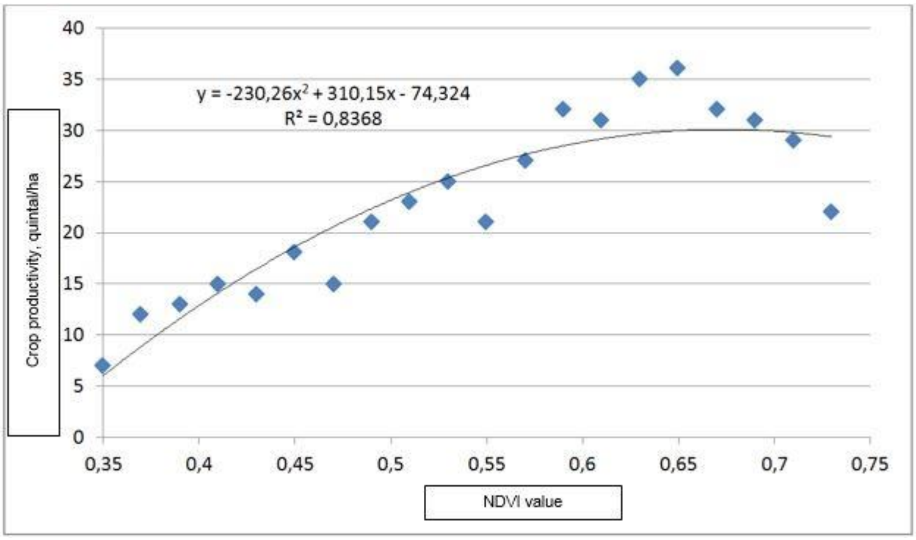

Figure 9. Regression model of crop harvest as a function of NDVI in vegetative–generative period

Conclusion

Using data from UAV (NDVI) facilitates rapid estimation of physiological state of crops and monitoring of vegetation development.

Data from UAV make it possible to forecast winter wheat productivity. This improves economic effect and financial planning.

On the basis of these data, the high precision regression model of winter wheat harvest as a function of NDVI was developed.

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